Contracting for Perennial Energy Crops Under Uncertainty and Costly Reversibility

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Selected Paper prepared for presentation for the 2016 Agricultural & Applied Economics Association, Boston, MA, July 31-August 2

Abstract

This paper addresses the impact that different contracts can have on a farmer's willingness to grow perennial crops, and both the risk the cost effectiveness of each type. Growing perennial energy crops such as poplar, requires large up front capital costs that are largely irreversible. It is also associated with highly volatile returns that can discourage cultivation. Traditional approaches to predict the entry threshold for a given project, such as NPV or Marshallian entry neglect to account for the uncertain, sunk, and intertemporal nature of these types of problems and thus under-estimate the profitability required for entry (Dixit and Pindyck, 1994). This study addresses this problem by using real options analysis. Higher degrees of uncertainty and irreversibility translate into higher premiums on entry due to the value of waiting for more information.

Our results suggest that different contracts can erode some of this premium. This study finds the specific type of contract that would trigger cultivation at the lowest possible cost to the biofuel plant. This study considers three different types of payment (performance, acreage, and cost index) to induce investment into poplar tree cultivation. It solves for the entry and exit net revenue thresholds under multiple levels and payment types, using real options. It then uses this threshold to calculate performance, acreage, and the total payment required for entry on a per ton of biomass basis.

Previous literature

Investment for cellulosic biofuel production continues to lag further behind mandates set by the first and second renewable fuel standard every year. The mandate of 16 billion gallons of cellulosic biofuel consumption by 2022 set forth in the second renewable fuel standard appears all but impossible at this point with 2.2 million gallons of cellulosic biofuel produced in 2015. Despite stated interest from both business and government there has been a reluctance to invest in both the biofuel plants themselves, and more importantly for this study, the cellulosic biomass to supply them. One possible explanation for this lack of investment is the interaction of sunk cost and uncertainty[1] about future returns on investment inherent within perennial energy crop production. Investment projects containing large sunk costs and volatile returns are good candidates for real options analysis (Dixit and Pindyck, 1994).

Converting an acre of agricultural land to poplar tree production is expensive to initiate, expensive to get out of, and contains considerable uncertainty about returns in the future as both yields and the opportunity cost of growing agricultural crops are uncertain. There have been several papers written that have looked at perennial crop investment in a real options context. These studies either look at the investment decision as is, in the face of all the uncertainty that the market and/or yield variability can create (Musshoff, 2012 ; Price and Wetzstein, 1999; Schatzki, 2003) , or discuss it in the context of different possible government policies (Regan, et al., 2015; Song, et al., 2011; Wolbert-Haverkamp and Musshoff, 2013).

Several common themes emerge from these papers. The first and most obvious being, the decision of incorporating uncertainty, irreversibility, and temporal flexibility into the decision making process in non-trivial and will lead to thresholds for entry well above a traditional NPV. Under their own base assumptions, all the previously mentioned papers found premiums above the traditional NPV threshold required for entry to anywhere between 19-138% for risk neutral individuals. (Price and Wetzstein, 1999; Schatzki, 2003; Regan, et al., 2015; Song, et al., 2011; Wolbert-Haverkamp and Musshoff, 2013).

[1] The definition for uncertainty varies by the literature category. This paper uses the definition of real options that is used within the real options literature. Uncertainty within this paper means that future outcomes are stochastic with a known distribution of potential outcomes.

Another common practice used in most of the papers was incorporating in the opportunity cost of land into the calculations for entry ((Regan, et al., 2015, Song, et al., 2011); (Wolbert-Haverkamp and Musshoff, 2013). Unlike many other types of investment projects in the real options literature, the land is assumed to either from the start to be under use for some sort of agricultural practice that is not perennial crop production, or be fallow and have the choice of growing agricultural crops instead of perennial crops. For a farmer to be willing to enter, they not only have to cover their fixed and operating costs, they also must cover what they could have made in profit by sticking with what they were currently growing such as corn.

Adding opportunity cost into the calculations not only increases the cost associated with the perennial crop investment, it also increases the amount of total uncertainty when deciding between the two projects since the return from growing traditional crops is itself also uncertain. Both profitability and opportunity cost have uncertain outcomes in the future and ignoring the uncertainty from the opportunity cost of the land will cause inaccurate calculations for trigger values.

The real options literature has established that large hysteresis in both investment and exit of perennial crop projects is caused by the uncertainty and irreversibility of such investments. While papers do exist that do discuss some potential government policies (Regan, et al., 2015; Song, et al., 2011; Wolbert-Haverkamp and Musshoff, 2013), the funding and commitment to these policies is itself largely uncertain. To stimulate investment the premiums on entry into poplar tree production must be lowered. Due to the previously mentioned drawbacks of government policy, this paper looks to draw insight from the well-established, but seldom combined with real options, perennial crop contract theory.

One approach to dealing with contracting for perennial energy crops is to use a "mechanism design approach". This approach attempts to optimize a function, typically a maximization of profits or minimization of costs for the biofuel plant "principle" while satisfying incentive compatibility and participation constraints for the farmer "agent". All else equal ,performance type payments such as paying per dry ton improve incentive compatibility for the farmers since there goals will be more in line with that of the plant but will hurt participation constraints as most farmers are risk averse and prefer contracts that reduce the amount of risk they are exposed to (Alexander, et al., 2012).

Another contracting approach used is modeling the distribution of possible future profitability for both the principal and agent under different types of contracts. Different contracts will affect both the total risk and the amount of risk that both the principal and agent are exposed to. Plants and especially farmers are considered to be risk averse thus would face a tradeoff between expected profits and risk to optimize their utility function. This approach is used in one paper that models different contract combinations of performance, acreage, and index payments (Yoder, et al., 2015). The Yoder paper finds that risk is mitigated to both parties under an acreage payment scheme that pays a farmer a fixed amount to grow biomass every year.

Both the previous contracting papers addressing investment in perennial energy crops have suggested that it is unlikely that an optimal perennial energy crop contract would have a variable output price completely at the mercy of the market (Alexander, et al., 2012 ; Yoder, et al., 2015). These papers both concentrated on contracts that had performance payments, acreage payments, and indexing payments. Due to these being the important contract types within the contracting literature, these will be the types of payment arrangements built into the real options analysis for this paper.

Methods

We consider one stochastic variable, net revenue, which is a function of two random components, yield and opportunity cost. Both of these variables follow a random walk. This contract assumes a pre-specified and contracted selling price for biomass. In the contract payments are made as a combination of acreage, performance, and cost indexing. Potential contract combinations are evaluated at different levels of both yearly acreage payments and cost index strengths. Net revenue per acre that would cause a farmer to enter and exit under all possible scenarios is then recovered using real options. These net revenue trigger values are used to recover the performance (price per dry ton), acreage (yearly fixed payment per acre/expected yield at entry), and cost index level (revenue neutral but impacts risk for both parties) that induce entry for a given contract. Expected welfare received by the biomass grower, is then calculated to find the most efficient contract for inducing investment. Table 1 explains the contract combinations that will be evaluated. The trigger value for entry and resulting farmer surplus is recovered for each of these.

Table 1: Trigger net revenue for entry and exit under different combinations of acreage payment and cost index strength

Trigger net revenue for entry and exit under different levels of acreage payment and cost index													
	F (acreage payment per acre per year)												
		$0	$20	$40	$60	$80	$100	$120	$140	$160	$180	$200	$220
α (strength of correlation between cost index and cost)	0	Performance	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage	Performance & acreage
	0.1	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.2	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.3	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.4	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.5	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.6	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.7	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.8	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	0.9	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3
	1	Performance & cost index	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3	all 3

This paper uses a slightly different definition of net revenue while solving the real options problem, for the ease of computation. To calculate entry and exit thresholds, net revenue R is measured as $R = [P * Y - c]$ where P is the fixed parameter price, Y is the stochastic variable yield, c is the stochastic opportunity cost of growing a corn soybean rotation on low value agricultural land. The stochastic nature of opportunity cost "c" will vary depending on the cost index strength α. The stronger α the lower the uncertainty associated with opportunity cost will be for the farmer, although its expected value will stay the same.

The profit flow of a type one contract can be measured as $\boldsymbol{\pi} = R - w - K + F$. Where w represents the operating cost, K represents the capital cost of investing in poplar tree production, and F is the yearly acreage payment for growing biomass. In our case c and w are separate since over half of the yearly operating cost in poplar tree production on low value agricultural land is tied to the opportunity cost of growing agricultural crops for which there is readily available data, the rest of operating cost is made up of numerous inputs such as fertilizer, pesticide, and management. These are assumed to be constant in the interest of simplifying the model while still focusing on the important aspects.

The nature of cellulosic biofuel production presents some unique challenges to this analysis. The first challenge is asymmetric uncertainty. A farmer considering the possibility of growing crops won't gain any value for waiting to see what happens to yield, since yield today is only dependent upon the yield yesterday if the crop is already planted. Opportunity cost uncertainty on the other hand will follow the random walk stochastic process critical for real options, whether the farmer has planted or not. This will lead to two different levels of uncertainty, just cost or both cost and yield. These levels of uncertainty are dependent upon if the farmer is in an idle or active state respectively for growing energy crops. Ignoring this asymmetric uncertainty will overestimate the value to waiting, and make the trigger value for entry artificially high. This will be addressed by using a different standard deviation to model our stochastic variable, net revenue, depending on if the state being discussed is idle or active. The standard deviation will also change for different levels of correlation in the cost index. This will also be modeled accordingly.

Secondly, this paper concentrates on the impact that contracting can have on a farmer in the context of how it impacts their uncertainty and ultimately premium for entry, but these contracts will also affect the amount of risk that the biofuel plant is exposed to. A contract that reduces risk for the farmer will typically increase it for the plant. Real options usually assumes economic actors are risk neutral and that risk only matters in the context of how it affects the value for waiting, but in reality risk matters for almost anyone making an investment. To accommodate this issue without diverging too far from the goal of this paper, finding the contract combination that induces entry of the farmer at the lowest possible cost, we calculate the distribution of NPV values for both the plant and farmer over twenty years over 3 representative contracts using an @Risk analysis.

These contracts include a heavily performance based contract ($\alpha = 0$ and $A = 0$) which is relatively safe for the plant and risky for the farmer, a moderately performance based contract ($\alpha = 0.3$ and $A = 115$) which is of moderate risk to both the plant and farmer, and a heavily acreage based contract ($\alpha = 0.6$, and $A = 230$) which is relatively risky for the plant and safe for the farmer. The plant taking on more of the farmer's risk will induce entry at a lower premium thus making the plant more profitable but it will also expose it to more risk.

A poplar tree growing operation can be in one of two states; idle where no trees are being grown, or the operation can be active where the farmer is growing poplar. Let us denote an idle project's discounted expected value by $V_0(R)$. For an idle project, this value is based on the option for the firm to enter the industry in the future. Normally it would also be based on the profitability of growing a corn-soybean rotation, but that is calculated into our version of net revenue. To avoid double counting opportunity cost, an idle project has no revenue or expenses, but has the option of earning a profit in the future if the option is exercised and the project is brought to an active state.

An investor that owns a project in an idle state could do one of two things, hold onto the option and activate the project if revenues are sufficiently high or sell the option to someone else and invest the proceeds. The former is represented by the equation $E_t[dV_0(R)]dt^{-1}$, where ε_t is the expected value of the project at time t. The latter is represented by the function $\delta V_0(R)$. δ represents the discount rate. The left hand side of equation one can be thought of as the return generated from selling the project and investing the proceeds. The right hand side is the expected capital gain of the project. Arbitrage in efficient markets would set these two returns equal:

$$\delta V_0(R) = E_t[dV_0(R)]dt^{-1} \tag{1}$$

Equation 1 is a Bellman equation and it must hold in efficient markets. It defines the entry trigger revenue. To solve for this revenue, we first need to find an expression for $dV_0(R)$. This is solved through the use of Ito's Lemma which is in essence a Taylor series expansion. We are left with:

$$\delta V_0(R) = \frac{\partial V}{\partial R}(\mu R) + \frac{\partial^2 V}{\partial R^2}\left(\frac{1}{2}\sigma^2 R^2\right) \tag{2}$$

Equation (2) represents a second order homogenous ordinary differential equation. Its solution is denoted as (Dixit and Pindyck, 1994):

$$V_0 = A_0 R^{-\alpha} + B_0 R^{\beta} \tag{3}$$

α and β are parameters that build the uncertainty modeled by Geometric Brownian Motion into the model, since there will be both two different standard deviations as a percent of net revenue (σ) depending on the state, parameters will be denoted in i but will have one value for active state (1) and one value for idle(0). More specifically $\sigma_0(c)$ and $\sigma_1(Y,c)$. δ denotes the discount rate. :

$-\alpha_i = 0.5[(1-2\mu\sigma_i\text{^}(-2)) - ((1-2\mu\sigma_i^{-2})^2 + 8\delta\sigma_i^{-2})^{.5}] < 0$

$\beta_i = 0.5[(1-2\mu\sigma_i^{-2}) + ((1-2\mu\sigma_i^{-2})^2 + 8\delta\sigma_i^{-2})^{.5}] > 1$

For the value of an idle state, A_0 and B_0 are unknown constants. $A_0R^{-\alpha_0}$ is the option value of changing states if revenue decreases, and $B_0R^{\beta_0}$ is the option value of switching to a different state if revenue increases. We drop $A_0R^{-\alpha_0}$ since the project has no value as R approaches zero.

As previously mentioned the operation can be in an active state, which is denoted V_1. We find V_1 through the same process used to find V_0. In an active state the farmer is paying operating cost w, earning performance based net revenue R, acreage based yearly fixed payment F, has a discount rate δ, and has the option of exiting $A_1R^{-\alpha}$ if revenue decreases :

$V_1(R) = R(\delta - \mu)^{-1} - w\delta^{-1} + A_1R^{-\alpha_1} + F\delta^{-1}$ (4)

To get to this active state the farmer must pay a fixed cost of K. A farmer will switch from the idle state to the active state once $V_1 - k = V_0$. These value functions will be driven by trigger revenue for entry R_h. We set this equality and its corresponding first order condition to get the first two equations we will eventually use to solve our system of equations.

$V_0(NR_h) = V_1(R_h) - k$ (5)

$V'_0(R_h) = V'_1(R_h)$ (6)

Once a farmer has entered they have the option to switch from an active state, back to an idle state if revenue is too low. This trigger revenue for exit is denoted R_l. They can switch back to an idle state if they pay a fixed cost L. This can be thought of as the cost of taking out the roots and getting the field back to the point being able to grow traditional crops. They will make this switch once:

$$V_1(R_l) = V_0(R_l) - L \quad (7)$$

$$V'_1(R_l) = V'_0(R_l) \quad (8)$$

Value functions 3 and 4 are substituted into their value matching and subsequently smooth pasting functions 5-8. To get our system of equations which are then solved in matlab numerically.

$$B_0 {R_h}^{\beta_0} = R_h(\delta - \mu)^{-1} - w\delta^{-1} + A_1 {R_h}^{\alpha} + F\delta^{-1} - k \quad (9)$$

$$A_1 {R_l}^{\alpha} + R_l(\delta - \mu)^{-1} - w\delta^{-1} = B_0 {R_l}^{\beta_0} - L \quad (10)$$

$$\beta_0 B_0 {R_h}^{\beta_0 - 1} = (\delta - \mu)^{-1} + \alpha_1 A_1 {R_h}^{\alpha - 1} \quad (11)$$

$$\alpha_1 A_1 {R_l}^{\alpha - 1} + (\delta - \mu)^{-1} = \beta_0 B_0 {R_l}^{\beta_0 - 1} \quad (12)$$

To this point, we have shown the contract accommodates both the performance component of the contract as well as the acreage component. The cost indexed element is modeled by changing the volatility of σ that is impacted by opportunity cost of land dependent upon the strength of the index. In other words the expected value of opportunity cost is \$124 for low value agricultural land, if the index strength is above zero the plant will pay the farmer more if opportunity cost is above \$124 and less if it is below it. This is a revenue neutral policy that decreases the degree of uncertainty that the farmer will have about their opportunity cost as the strength of the index increases. This interaction between index strength and σ was calculated running @risk simulations in Matlab is shown in Table 2. Stronger indexes decrease uncertainty for net revenue in both states but have a disproportionate effect in the idle state since that is only being affected by volatility in opportunity cost as where the active state is affected by both yield and opportunity cost uncertainty.

Table 2: Standard deviations as a percentage of net revenue in net revenue for idle and active states under different cost index strengths.

Index Strength "α"	σ_0	σ_a
0	0.1795	0.3196
0.1	0.1615	0.3075
0.2	0.1437	0.3007
0.3	0.1257	0.2923
0.4	0.1077	0.2841
0.5	0.0897	0.2771
0.6	0.0719	0.2719
0.7	0.0538	0.2680
0.8	0.0359	0.2653
0.9	0.0179	0.2627
1	0.0000	0.2622

As previously mentioned, the trigger value of net revenue for entry is what is solved for in the real options analysis but to recover the individual components of a given contract, additional calculation is needed. The payment per acre that induces entry must be broken down into performance and acreage components on a per dry ton basis as that is the form that the plant cares about. The net revenue threshold for entry is what the farmer needs to be paid, after their opportunity cost has been covered.

To calculate this, it is assumed that the plant will pay the farmer the expected value of opportunity cost every year as a fixed payment and anything in addition to this will be the farmer's performance or acreage payment. The performance payment per dry ton to induce entry for a given contract is calculated as $\frac{R_h}{E[yield]}$, where E denotes the expectation, which this analysis assumes to be 3.92 dry tons per acre. This was calculated as the average of expected yearly biomass accumulation from the studies (James, et al., 2010; Downing, et al., 2011; Kells and Swinton, 2014; Lazarus, et al., 2015).

The acreage payment per dry ton at entry is calculated as $\frac{A}{E[yield]}$. The final component of cost per dry ton is the plant covering the biomass growers opportunity cost, the expected value of this will be the same over all contracts and is calculated as, $\frac{C}{E[yield]}$, where C is assumed to be $124 an acre which is the projected net revenue of growing a corn soybean rotation on low value agricultural land in Indiana. (Dobbins, et al, 2015)

Results

The results from different combinations of contracting payment are found in Tables 3-5 and Figure 1. They suggest that increasing an acreage payment to the farmer will more than offset the performance payment required to induce entry, except under very extreme cost indexes ($\alpha \geq 0.7$) where, there is little option value for waiting to enter but considerable option value of waiting to exit. Another result is that stronger cost indexes reduce the premium required for entry considerably as they eliminate portions of opportunity cost uncertainty.

The affects for both acreage payments and cost indexing payments are not constant, they interact with one another. For instance, a marginal payment for acreage is considerably more effective for reducing the premium on entry when there is no cost index than when there is a stronger cost index. The final interpretation to be drawn from figure 1 is that the effect for acreage payments is itself not constant. Relatively speaking, the marginal effect of acreage payment on the reduction of premium required for entry is much more pronounced for high levels of acreage payments than low levels of acreage payments.

Table 3: Entry/exit thresholds and payments when, α=0 and σ_1=0.18, σ_2= 0.32

strength of index "α"	acreage payment "A"	Rh	Rl	performance price per dt	Expected acreage payment per dt at entry	Expected total cost per dt at entry	Expected farmer surplus
0	$ -	$ 308.94	$ 67.32	$ 78.81	$ -	$ 110.32	$ 2,977.06
0	$ 20.00	$ 287.96	$ 58.90	$ 73.46	$ 5.10	$ 110.07	$ 2,852.56
0	$ 40.00	$ 266.61	$ 50.60	$ 68.01	$ 10.20	$ 109.72	$ 2,718.81
0	$ 60.00	$ 244.84	$ 42.44	$ 62.46	$ 15.31	$ 109.27	$ 2,574.56
0	$ 80.00	$ 222.56	$ 34.42	$ 56.78	$ 20.41	$ 108.69	$ 2,417.56
0	$ 100.00	$ 199.64	$ 26.58	$ 50.93	$ 25.51	$ 107.94	$ 2,244.56
0	$ 120.00	$ 175.90	$ 18.95	$ 44.87	$ 30.61	$ 106.99	$ 2,051.06
0	$ 140.00	$ 150.98	$ 11.58	$ 38.52	$ 35.71	$ 105.73	$ 1,828.06
0	$ 160.00	$ 124.23	$ 4.58	$ 31.69	$ 40.82	$ 104.01	$ 1,559.31
0	$ 170.00	$ 109.65	$ 1.21	$ 27.97	$ 43.37	$ 102.84	$ 1,394.81
0	$ 180.00	$ 93.57	$ -	$ 23.87	$ 45.92	$ 101.29	$ 1,192.81
0	$ 200.00	$ 60.92	$ -	$ 15.54	$ 51.02	$ 98.07	$ 776.56
0	$ 220.00	$ 28.28	$ -	$ 7.21	$ 56.12	$ 94.84	$ 360.56
0	$ 235.00	$ 3.79	$ -	$ 0.97	$ 59.95	$ 92.42	$ 48.31

Table 4: Entry/exit thresholds and payments when, α=0.3 and σ_1=.013, σ_2 = 0.29

strength of index "α"	acreage payment "A"	Rh	Rl	performance price per dt	Expected acreage payment per dt at entry	Expected total cost per dt at entry	Expected farmer surplus
0.3	$ -	$ 268.53	$ 67.28	$ 68.50	$ -	$ 100.01	$ 1,966.81
0.3	$ 20.00	$ 249.93	$ 59.06	$ 63.76	$ 5.10	$ 100.36	$ 1,901.81
0.3	$ 40.00	$ 231.04	$ 50.91	$ 58.94	$ 10.20	$ 100.65	$ 1,829.56
0.3	$ 60.00	$ 211.79	$ 42.88	$ 54.03	$ 15.31	$ 100.84	$ 1,748.31
0.3	$ 80.00	$ 192.12	$ 34.95	$ 49.01	$ 20.41	$ 100.92	$ 1,656.56
0.3	$ 100.00	$ 171.91	$ 27.16	$ 43.85	$ 25.51	$ 100.87	$ 1,551.31
0.3	$ 120.00	$ 151.01	$ 19.52	$ 38.52	$ 30.61	$ 100.64	$ 1,428.81
0.3	$ 140.00	$ 129.14	$ 12.06	$ 32.94	$ 35.71	$ 100.16	$ 1,282.06
0.3	$ 160.00	$ 105.76	$ 4.82	$ 26.98	$ 40.82	$ 99.30	$ 1,097.56
0.3	$ 170.00	$ 93.10	$ 1.31	$ 23.75	$ 43.37	$ 98.62	$ 981.06
0.3	$ 180.00	$ 78.95	$ -	$ 20.14	$ 45.92	$ 97.56	$ 827.31
0.3	$ 200.00	$ 51.41	$ -	$ 13.11	$ 51.02	$ 95.64	$ 538.81
0.3	$ 220.00	$ 23.86	$ -	$ 6.09	$ 56.12	$ 93.71	$ 250.06
0.3	$ 235.00	$ 3.20	$ -	$ 0.82	$ 59.95	$ 92.27	$ 33.56

Table 5 Entry/exit thresholds and payments when, $\alpha = 0.3$ and $\sigma_1 = 0.05$, $\sigma_2 = 0.27$.

strength of index "α"	acreage payment "A"	Rh	Rl	performance price per dt	Expected acreage payment per dt at entry	Expected total cost per dt at entry	Expected farmer surplus
0.7	$ -	$ 217.64	$ 66.59	$ 55.52	$ -	$ 87.03	$ 694.56
0.7	$ 20.00	$ 202.39	$ 58.73	$ 51.63	$ 5.10	$ 88.24	$ 713.31
0.7	$ 40.00	$ 186.90	$ 50.92	$ 47.68	$ 10.20	$ 89.39	$ 726.06
0.7	$ 60.00	$ 171.11	$ 43.15	$ 43.65	$ 15.31	$ 90.46	$ 731.31
0.7	$ 80.00	$ 155.05	$ 35.44	$ 39.55	$ 20.41	$ 91.47	$ 729.81
0.7	$ 100.00	$ 138.52	$ 27.78	$ 35.34	$ 25.51	$ 92.35	$ 716.56
0.7	$ 120.00	$ 121.46	$ 20.17	$ 30.98	$ 30.61	$ 93.10	$ 690.06
0.7	$ 140.00	$ 103.61	$ 12.64	$ 26.43	$ 35.71	$ 93.65	$ 643.81
0.7	$ 160.00	$ 84.57	$ 5.14	$ 21.57	$ 40.82	$ 93.90	$ 567.81
0.7	$ 170.00	$ 74.31	$ 1.41	$ 18.96	$ 43.37	$ 93.83	$ 511.31
0.7	$ 180.00	$ 63.34	$ -	$ 16.16	$ 45.92	$ 93.58	$ 437.06
0.7	$ 200.00	$ 41.24	$ -	$ 10.52	$ 51.02	$ 93.05	$ 284.56
0.7	$ 220.00	$ 19.14	$ -	$ 4.88	$ 56.12	$ 92.51	$ 132.06
0.7	$ 235.00	$ 2.57	$ -	$ 0.66	$ 59.95	$ 92.11	$ 17.81

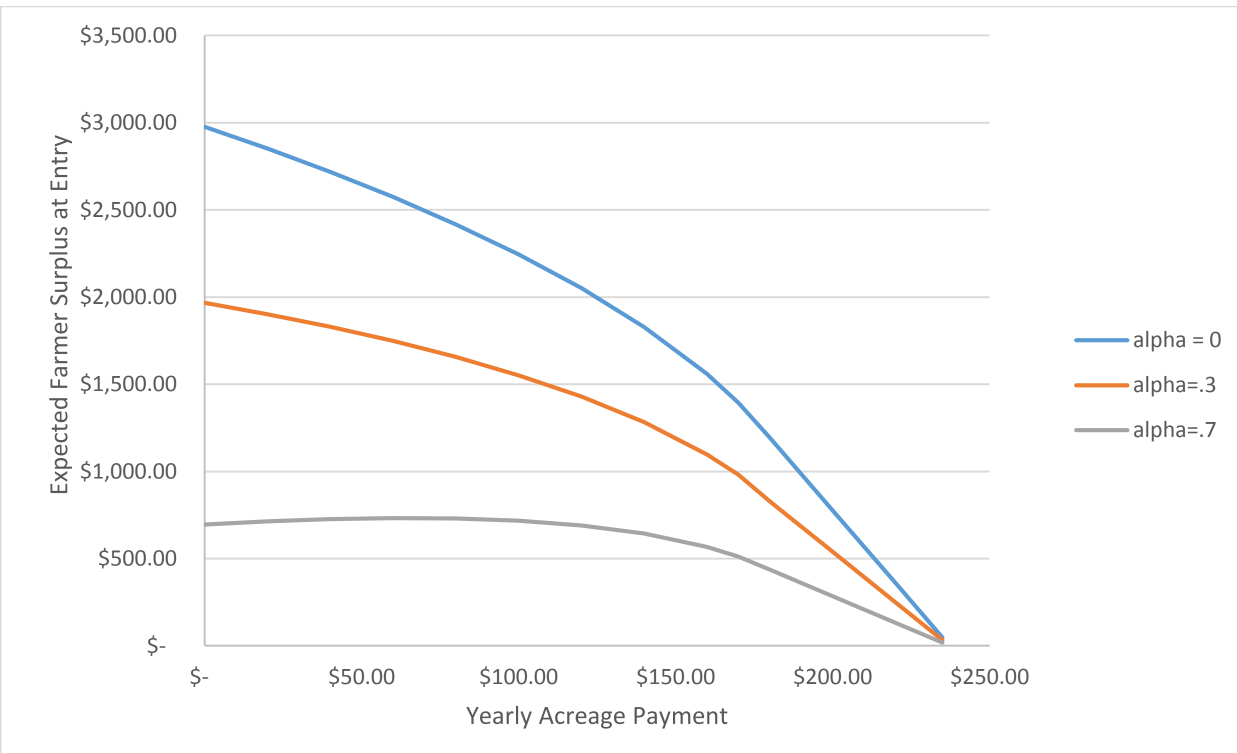

Fig 1. Expected farmer surplus under different levels of acreage payment a cost index strengths

Figure 2 shows the consequences of an asymmetric uncertainty assumption. Our results from the specification of asymmetric uncertainty are compared to the traditional assumption of constant uncertainty and an intermediate assumption of asymmetric uncertainty that has values of σ_0 and σ_1 that are closer to one another than the σ_0 and σ_1 used in our analysis. The gray line reflects the current assumptions about relevant uncertainty within an idle state (σ_0) and an active state (σ_1). The blue line is the line that would occur if the traditional assumptions about symmetric uncertainty were assumed. The premium for entry under the symmetric uncertainty assumption at a zero acreage and non-indexed payment type is more than twice as high as the chosen model. The orange line represents uncertainty that is still asymmetric but has half the gap between the sigmas that the current assumptions have. Figure 2 illustrates two important ideas, 1. The effect of building asymmetric uncertainty into the model is a significant one. 2. This difference in Iso-entry line slopes is the cause of trigger values for entry, and their corresponding expected farmer's surplus not to mesh perfectly with the theory for high levels of indexing ($\alpha \geq .7$).

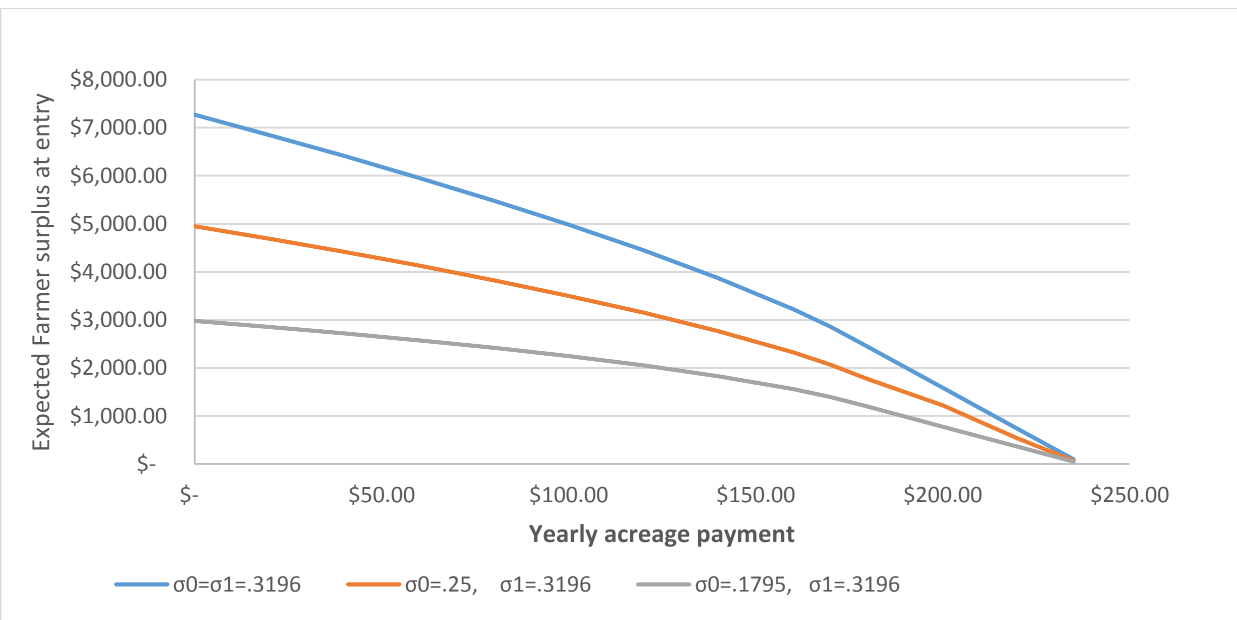

Fig 2. Expected farmer surplus, for different asymmetries in uncertainty and acreage payment at an index strength of zero

Figure 3 shows the differences in risk that the biofuel plant is subjected to under different contract formulations. From the plants perspective performance payment per dry ton itself is not risky at all since they know exactly what they will pay per dry ton and will be treated as fixed. They know they will pay exactly $\frac{R_h}{3.92}$ no matter what the yield is in a given year. For the plant, acreage payment carries risk with it since they are paying a given payment regardless of yield, for high yields the plant benefits and for low yields they are harmed. Expected cost per dry as a payment on acreage is $\frac{A}{E[yield]}$ where yield is log-normally distributed with a mean of 3.92, standard deviation of 0.59, and a yearly drift rate of 1% caused by improvements in farming practices.

Payment to the farmer for opportunity cost is calculated separately due to differences in indexing. Expected cost per dry ton as a payment for opportunity cost is calculated as $\frac{(1-\alpha)124*(1+l)^t}{E[yield]} + \frac{\alpha E[c]}{E[yield]}$ where opportunity cost c is log normally distributed with mean 124, standard deviation 30, and a yearly drift rate of $l = 1\%$ caused by increases in the value of farming a corn soybean rotation. t denotes the year. In the context of payment for opportunity cost, the plant is subject to more risk when they offer cost indexing compared to when they don't. Fixed payments for cost will always be affected by yield but indexing also adds in a stochastic element for the payment itself.

In Figure 3, green denotes the "safe contract for the plant" which is specified as ($78.81 per dry ton, $\alpha = 0$, and $A = 0$). Blue denotes the intermediate risk contract for the plant with ($25.25 per dry ton, $\alpha = 0.3$, and $A = 115$). Red signifies the risky contract for the plant with ($2.18 per dry ton, $\alpha = 0.6$, and $A = 230$).

Figure 3 shows that a biofuel plant can significantly increase its expected NPV by taking the uncertainty themselves albeit for more risk. The downside risk however is relatively low even under the most risky contract since it moves the expected return so much higher in the first place. A biofuel plant would have to be very risk averse to not take a contract that is heavily acreage and or index based.

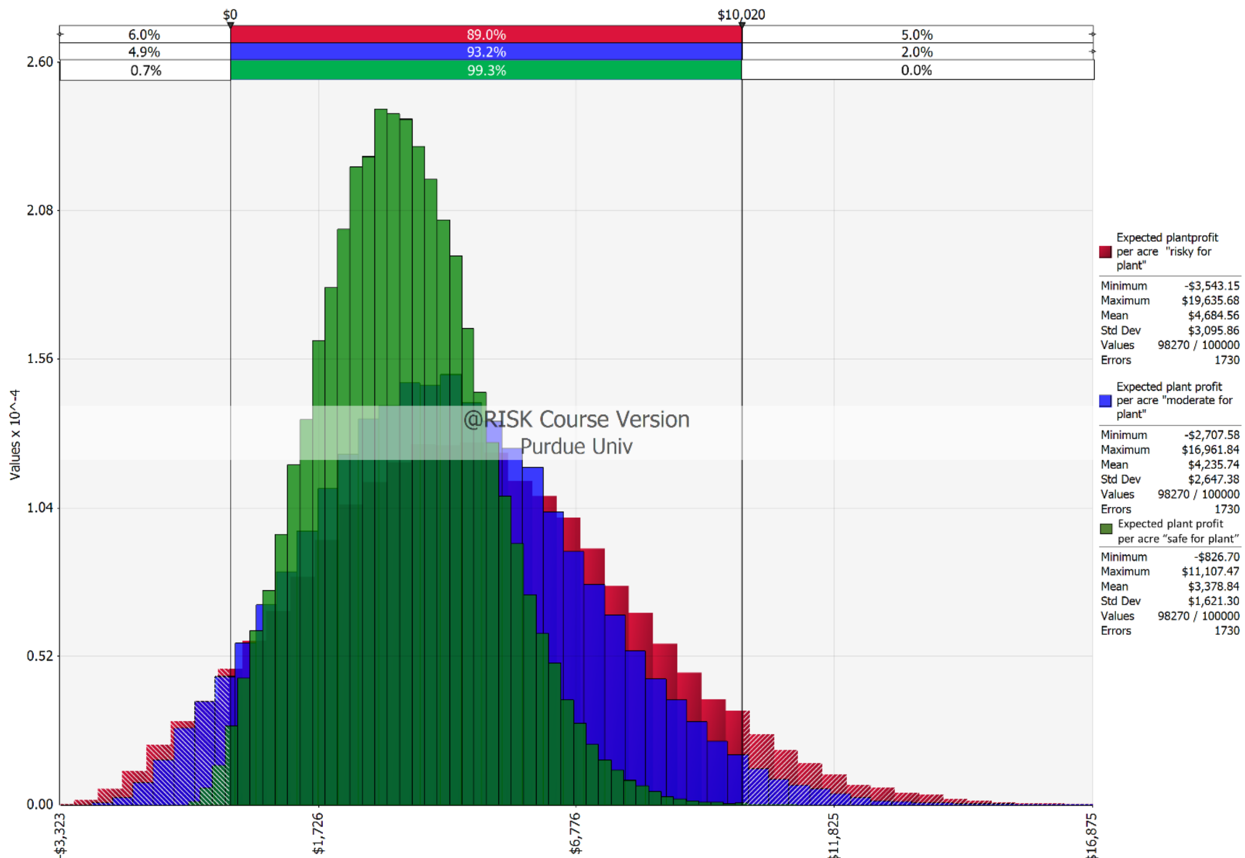

Fig 3. Distribution of potential NPV outcomes for the plant under three different contracts

Figure 4 compares the same three contracts from the farmers risk perspective. Performance payments add risk to the farmer and acreage payments and cost indexes reduce risk. Blue denotes the "risky contract for the farmer" which is specified as (\$78.81 per dry ton, $\alpha = 0$, and $A = 0$).

green denotes the intermediate risk contract for the farmer with (\$25.25 per dry ton, $\alpha = 0.3$, and $A = 115$). Red signifies the safe contract for the farmer with (\$2.18 per dry ton, $\alpha = 0.6$, and $A = 230$).

The results for the farmer's preference are similar to that of the plants. In the absence of extreme risk aversion, the farmer is best off taking on a riskier contract, since the expected value is shifted so far to the right. However, their profitability is much more volatile than that of the plants under different contracts, so if there was some sort of constant risk aversion for both the plant and farmer, the negotiating may end at a point with the plant taking on the majority of the risk as it does not affect its profits in as volatile a way as it does the farmer. Also despite the differences in expected value, in a real options context all three of these contracts leave the farmer indifferent between entering and not entering.

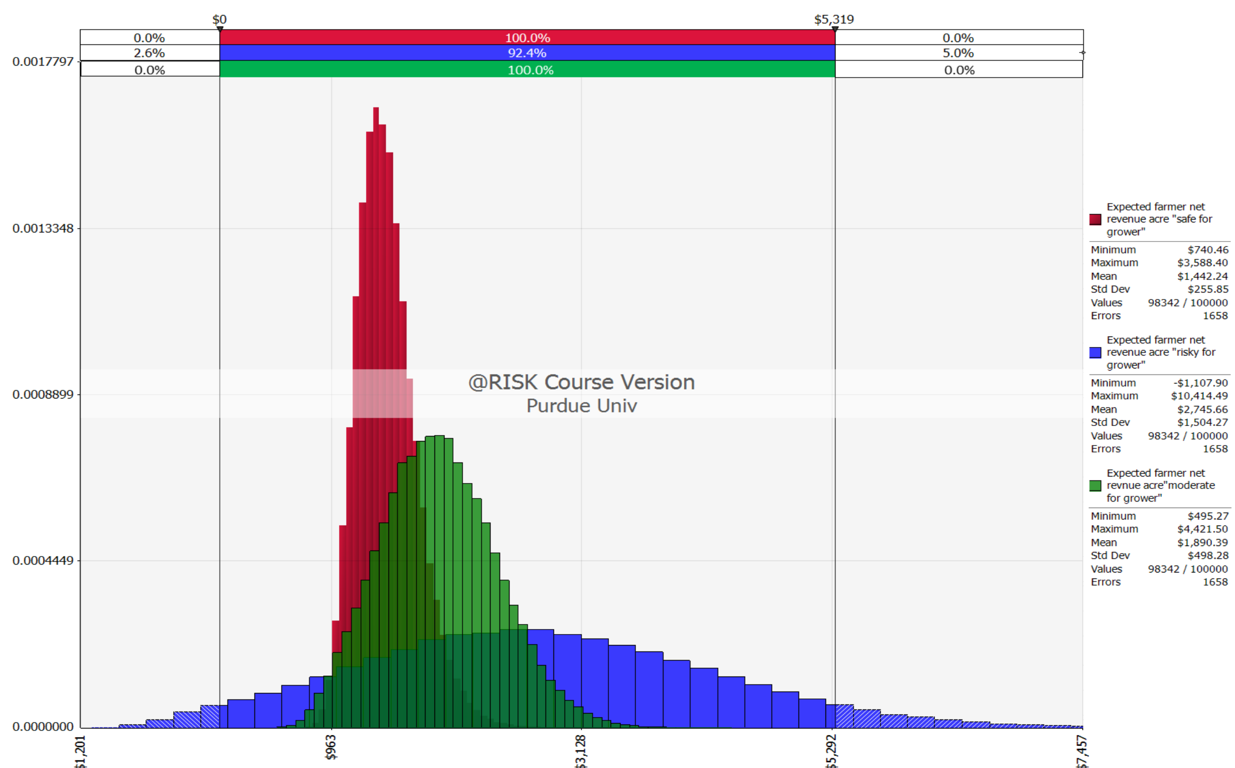

Fig 4. Distribution of NPV outcomes for farmers under three different contract combinations.

Conclusions

Investment in cellulosic biofuel production has continually fallen well short of the renewable fuel standard mandate. Before these plants can even be built they must obtain a reliable low cost source of bio feedstock. Due to the uncertainty and irreversibility associated with perennial energy crop production, premiums far in excess of the economic cost of production are required to induce entry. Our calculations put the uncontracted premium for entry at 38% or $30 per dry ton above the Marshallian entry point. Contracting can alleviate much of this problem. Specifically contracts that reduce the amount of risk that the farmer is exposed to reduce the premium most effectively since it reduces the option value of waiting for more information and in the extreme case actually brings a farmers entry threshold back in line with a Marshallian level of entry.

An acreage contract that exactly guarantees all costs to the plant are covered will bring the entry threshold back in line with the Marshallian value for entry. Inducing entry at the lowest cost possible to the plant would involve an acreage payment of approximately $238, if they chose this extreme they would not index as it would only give the plant additional risk without reducing the premium they paid to the farmer at all. However, if the plant did not want all of the risk but wanted to cheaply reduce the premium for entry they may want to increase their cost index as it is cost neutral for them and reduces the premium on entry considerably for the farmer.

This paper ignores the moral hazard problem. Moral hazard occurs when an agent knows more about their own actions than the principal does and has incentives that are not compatible with the principal's. For simplicity, consider a contract where a farmer's payment for growing biomass is based only on their acreage. Both the farmer and the plant want to maximize their own profits. The biofuel plant does this by acquiring enough biomass as cheaply as possible so it can run its plant at capacity, and the farmer does this by minimizing their production cost. In this case their incentives are not compatible. Also the plant does not know if a low yield is caused by the farmer intentionally shirking their duties by using less inputs such as fertilizer or an event beyond the farmers control such as bad weather.

This combination of incentive incompatibility and asymmetric information creates a moral hazard for the farmer to produce less biomass than is economically efficient in order to minimize its production cost. If the farmer is "insured" against low payment because of bad yield they will do less to ensure the high yields that would be optimal for the plant and society as a whole. This problem will be addressed in future research by adjusting the model to accommodate a performance penalty that increases with the amount of guaranteed payment.

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